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Radial Growth in Grand Fir and Douglas-fir Related to Defoliation by the Douglas-fir Tussock Moth in the Blue Mountains Outbreak

B.E. Wickman, D.L. Henshaw, and S.K. Gollob

Acknowledgments

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Metric Conversions

1 centimeter = 0.4 inch
1 hectare = 2.5 acres

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Reference Abstract

Wickman, B. E., D. L. Henshaw, and S. K. Gollob.
1980. Radial growth in grand fir and Douglas-fir related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA For. Serv. Res. Pap. PNW-269, 23 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Radial growth reduction related to amount of tree defoliation was studied following a severe tussock moth outbreak. Growth sharply declined the year after defoliation began, and amount of decline was proportional to percent defoliation. Growth recovery began the year after defoliation ceased and radial increment had returned to pre-outbreak levels 5 years after defoliation.

KEYWORDS: Increment (radial), defoliation damage, insect damage (-forest, Douglas-fir tussock moth, Orgyia pseudotsugata, grand fir, Abies grandis, Douglas-fir, Pseudotsuga menziesii, Oregon (Blue Mountains), Washington (Blue Mountains).

Research Summary
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Radial growth of grand fir, *Abies grandis* (Dougl. ex D. Don) Lindl., and Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, was measured following an outbreak of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), in the Blue Mountains of Oregon and Washington. All dominant and co-dominant trees were sampled from a series of plots established in 1972-73 to study the relationship of tree damage to tussock moth larval densities. Defoliation estimates made in 1972-73 were related to growth reduction of individual trees and stands. Adjustments were made to deduct losses due to environmental effects from gross growth reductions. We found that growth declined rapidly the year after defoliation began and reached its lowest point the 2d year after defoliation (1974). Radial growth recovery began in 1975 and had nearly returned to pre-outbreak levels by 1978. Environmental effects, especially from sub-normal precipitation, compounded the effects of defoliation during the outbreak and late recovery periods.

Percent defoliation was a good predictor of growth reduction with losses proportional to severity of defoliation. A regression model comparing pre- and post-outbreak growth was developed for assigning expected growth declines to individual tree defoliation categories. Growth decline was most pronounced and similar for trees suffering 50-percent or more defoliation.

Grand fir in this category suffered a net growth reduction of 57.9 percent and Douglas-fir a net growth reduction of 57.4 percent. Stand growth reductions were also proportional to stand defoliation severity. The pattern of growth decline and recovery for the four stand defoliation classes--heavy, moderate, light, and very light--conformed to that of individual tree defoliation categories.

Contents

Introduction

The Douglas-fir tussock moth (DFTM), Orgyia pseudotsugata (McDunnough), is an important defoliator of Douglas-fir, Pseudotsuga menziesii var. glauca (Beissn.) Franco, and true fir, Abies spp., forests in western North America. Periodic outbreaks have caused severe timber losses. Tree mortality accounts for most of the loss (Wickman 1978a), but top-kill and reduced radial growth may add significantly to the damage.

The decline of white fir growth caused by DFTM defoliation is one of the most drastic on record for a forest defoliator (Koerber and Wickman 1970). The radial growth configurations are so distinctive that old outbreaks can be identified from increment cores or discs from host trees (Wickman 1963, Brubaker 1978).

Previous studies of white fir defoliated by DFTM in California have shown severe radial increment loss during and immediately after defoliation (Wickman 1963). The growth reduction was also related to degree of defoliation, with trees defoliated 75-90 percent suffering more than double the growth reduction of trees defoliated less than 25 percent. Growth recovery was usually not complete until 4 years after defoliation. Growth measurements had not been made of grand fir, Abies grandis (Dougl. ex D. Don) Lindl., or Douglas-fir after tussock moth defoliation so the pattern of radial increment loss and number of years of growth loss was unknown. It was suspected that grand fir reacts similarly to white fir, but the response of Douglas-fir was completely unknown.

A recent extensive outbreak in the Blue Mountains of Oregon and Washington offered the opportunity to study tree damage resulting from defoliation by extremely dense populations of DFTM. The objective of studies begun in 1972 was to use defoliation intensity in 1972 and 1973 as a predictor of tree damage during and after the outbreak. Two important forms of damage, tree mortality and top-kill, have already been summarized from this study (Wickman 1978a). The three forms of damage have also been mathematically represented in the DFTM outbreak model (Overton and Colbert 1978). This paper summarizes the effects of defoliation on radial growth during and immediately after the outbreak.

Methods

Location and Defoliation Classes

A series of 1/50th-acre damage plots was established in conjunction with six replicated tussock moth population study areas (Mason 1976) in the Blue Mountains to study the effects of defoliation (fig. 1). The area of study covered a 100-km transect of the tussock moth outbreak on the Umatilla and Wallowa-Whitman National Forests and included four additional heavily defoliated areas not included in the population study. The Forest Service mapped the outbreak from the air in 1972 (Graham et al. 1975) and stratified it into four defoliation classes; heavy, moderate, light, and very light. In addition, five individual tree defoliation classes as shown in figure 2 were used based on the percent of crown length totally defoliated (Wickman 1978a). Defoliation estimates of each plot tree were recorded as one of the seven classes immediately after the year of most intense defoliation (1972 or 1973).

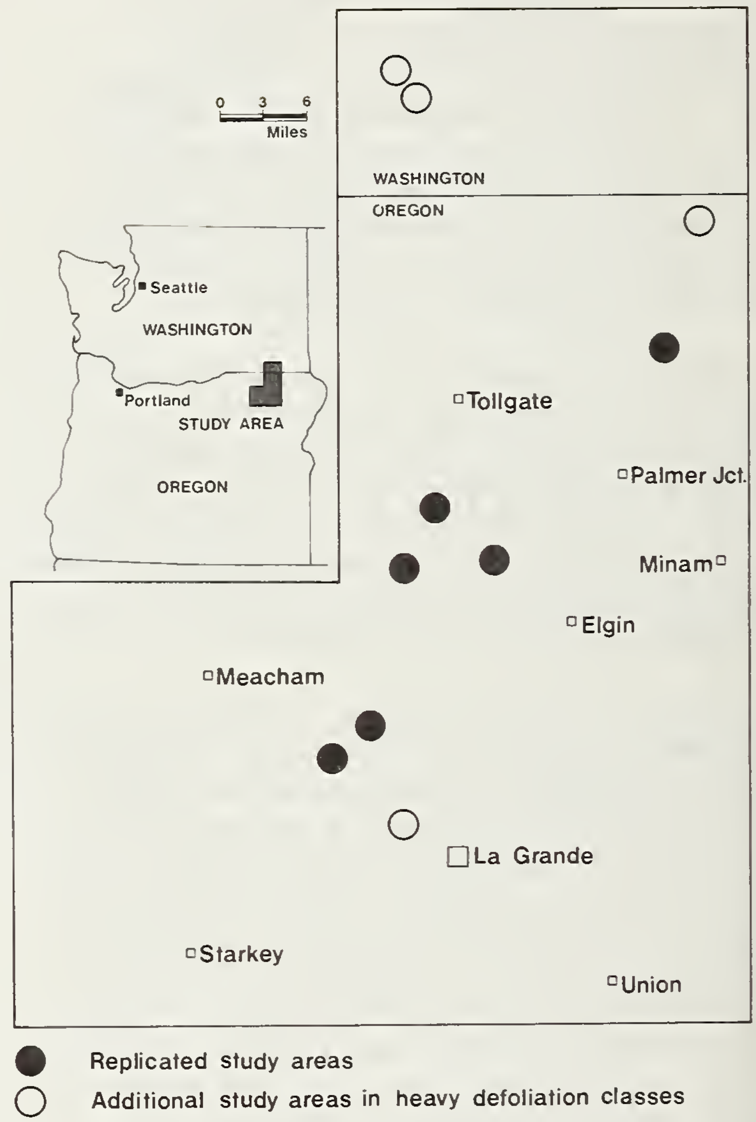

Figure 1.--Location of tree-damaged plot clusters in northeastern Oregon and southeastern Washington.

Sampling Techniques

Clusters of 10-15 damage plots were systematically established at each of the 22 populations study points and at some additional heavily defoliated areas. Every tree over 1-in d.b.h. on the 1/50th-acre circular plots was tagged, measured, and its defoliation estimated. Complete information on plot establishment, tree measurements, and examinations is given in detail in Wickman's (1978a) publication.

Figure 2.--Defoliation classes used in estimates, for individual trees, of percent of crown totally defoliated, 1972-73. Inset shows partial defoliation of lower branches.

At the end of the 1977 and 1978 growing seasons (late August through mid-September), increment cores were taken from every dominant and co-dominant grand fir and Douglas-fir on the plots. In addition, one dominant or co-dominant non-host tree (if present) was cored on each plot. Twenty-one mature ponderosa pine were sampled from a pine stand on a dry ridge (sensitive site) in the outbreak area to compare general tree growth patterns to climate (Fritts 1976). Non-defoliated host trees were cored from each of five check areas contiguous with and adjacent to the outbreak. Controls were as close as 1 kilometer and never further than 8 kilometers from defoliated stands. A breakdown of sample trees follows:

	No. trees
Defoliated host trees (grand fir and Douglas-fir) on plots	530
Non-defoliated host trees off plots	70
Non-host trees on plots (pine, larch, spruce)	89
Non-host trees (pine) on sensitive site	21

Two increment cores were taken per tree at d.b.h., except trees defoliated 50 percent or more had four cores taken in 1978 to help account for partially missing rings. The cores came from two quadrants at 90 degrees, usually the north and west if possible, as suggested by Fritts (1976). Cores were taken to the pith to include the total age of the tree in 1977, and cores including only the last 12 years were taken in 1978.

A Bannister incremental measuring machine (fig. 3) was used to measure annual increment on the cores to the nearest 0.01 mm as described by Stokes and Smiley (1968). Measurements were automatically printed on tape and later punched on cards for computer analysis.

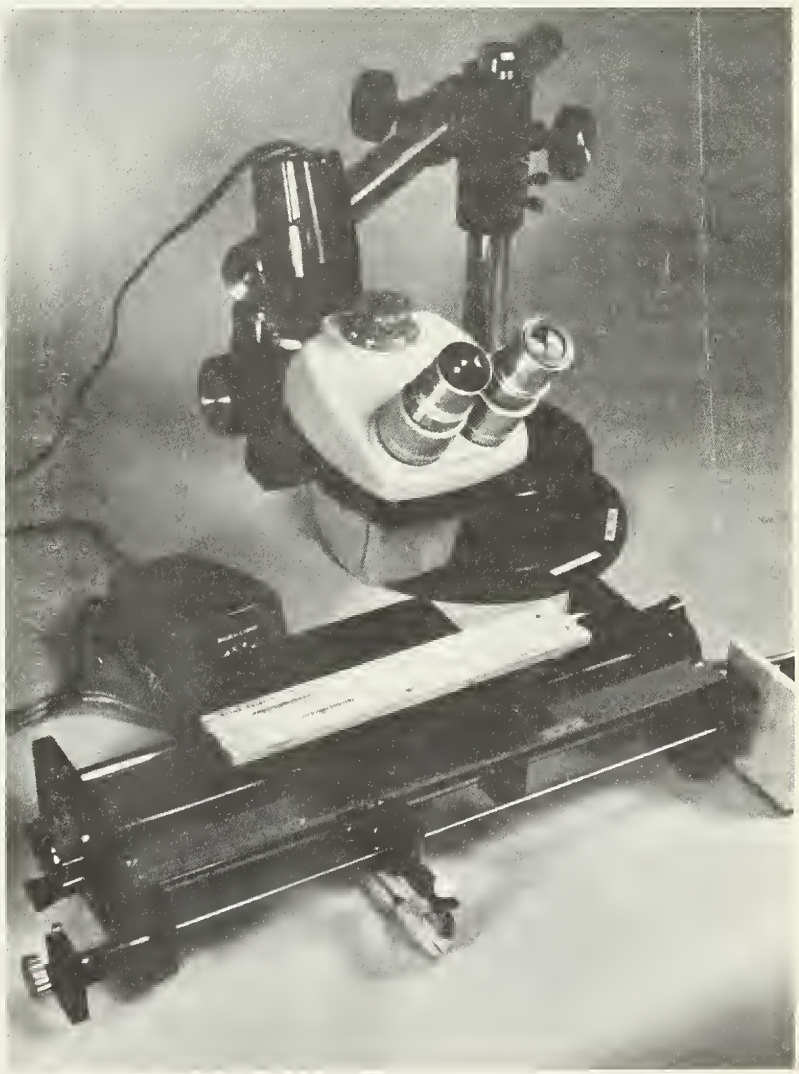

Figure 3.--A Bannister dendrochronograph used to measure annual growth on increment cores.

Analysis

Data were summarized and then graphed to show growth patterns of trees in individual tree defoliation classes, in each of the four aerially mapped defoliation classes, and in the four defoliation classes stratified by ground measurements. Diameter growth at d.b.h. is used as the principal growth parameter; however, basal area growth increment at d.b.h. was also examined. An example using this method is given for comparison on page 6.

A method was developed to estimate percent radial growth reduction for individual tree defoliation categories. Nondefoliated host sample trees are used to detect changes in growth patterns due to general environmental conditions from the pre-outbreak through the outbreak growth period. These patterns are assumed to hold true for defoliated host trees, and are used to obtain expected growth during the outbreak period. Then, actual growth of defoliated trees during the outbreak period is compared with the estimated expected outbreak growth to determine percent growth loss. An equation is derived to estimate this growth loss. Using this method, percent radial growth loss is determined based on diameter increments and on basal area increments.

A comparison of growth rates among individual tree defoliation categories using regression analysis and analysis of covariance was conducted. Regressions of post-outbreak growth on pre-outbreak growth are examined for each of these defoliation classes and tested for significance. An analysis of covariance was then used to test for differences among these linear relationships. When statistically examining the growth characteristics of individual trees, we are assuming independent random sampling of trees even though trees occur in groups by plot clusters.

Results and Discussion

Growth Related to Individual Tree Defoliation

Defoliated Tree Classes

The downward trend in growth of defoliated trees began in 1972, but may have been due more to environmental factors than to defoliation (fig. 4a-b). By 1973, there were sharp declines in growth for all defoliation categories; and in 1974, the year defoliation ceased, growth reached its lowest point. In 1975, growth started to increase and this continued until 1978, when growth returned to normal levels for all but the most severely defoliated trees. Depression of growth was directly proportional to defoliation with the most severely defoliated trees (both grand fir and Douglas-fir) exhibiting the greatest growth loss. The same relations are apportioned by 5-year periodic annual increments (fig. 5a-c). This is easier to decipher because four, 5-year periods of growth--three before the outbreak, and one each during and immediately after--smooth annual variation and for Douglas-fir particularly help define relationships.

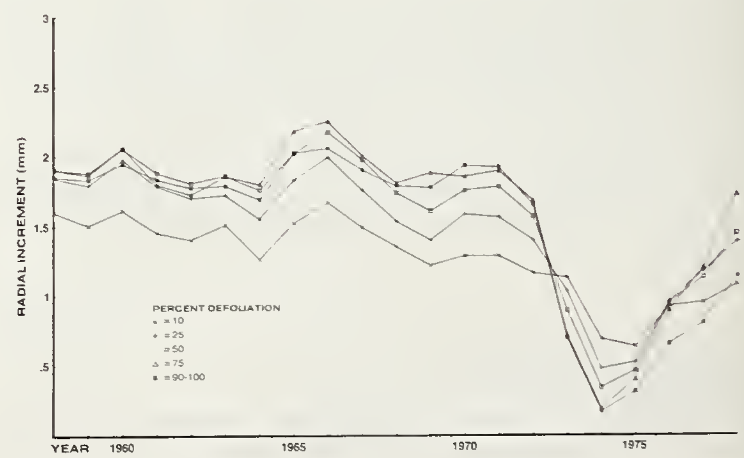

Figure 4a.--Grand fir average radial growth of individual tree defoliation classes.

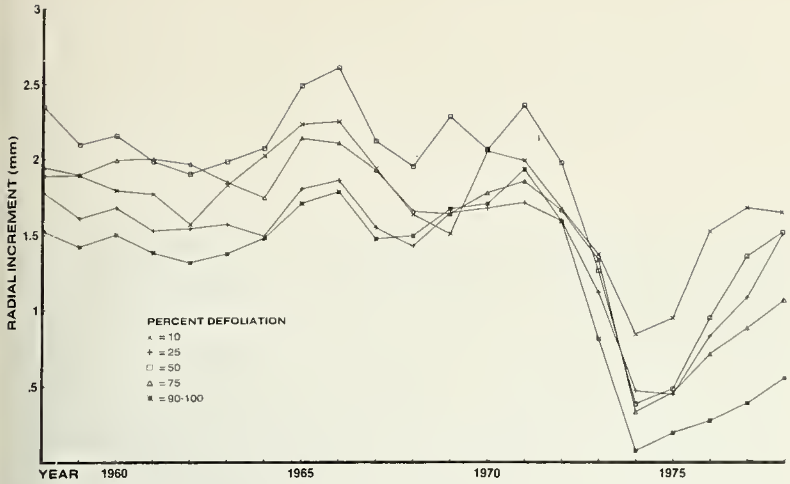

Figure 4b.--Douglas-fir average radial growth of individual tree defoliation classes.

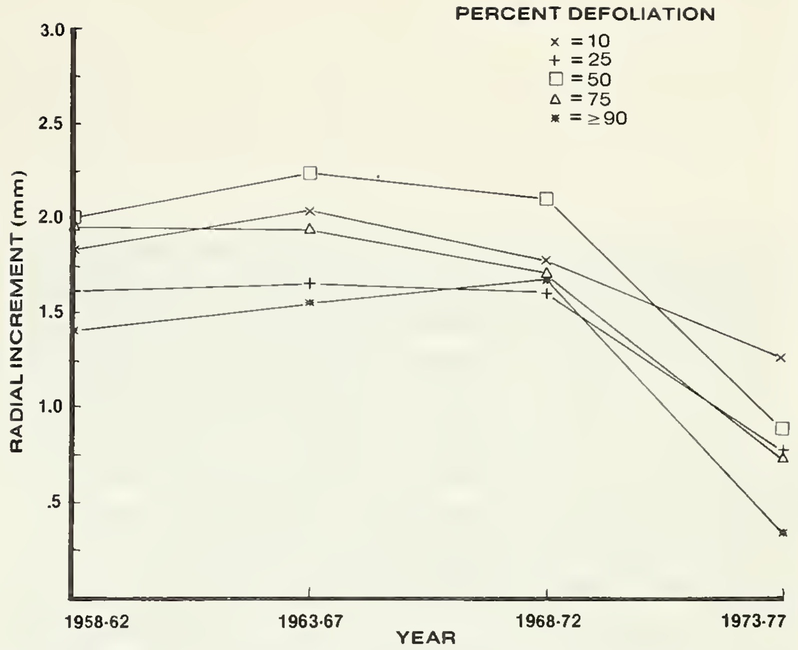

Figure 5b.--Douglas-fir average annual growth of individual tree classes in 5-year periodic annual increments.

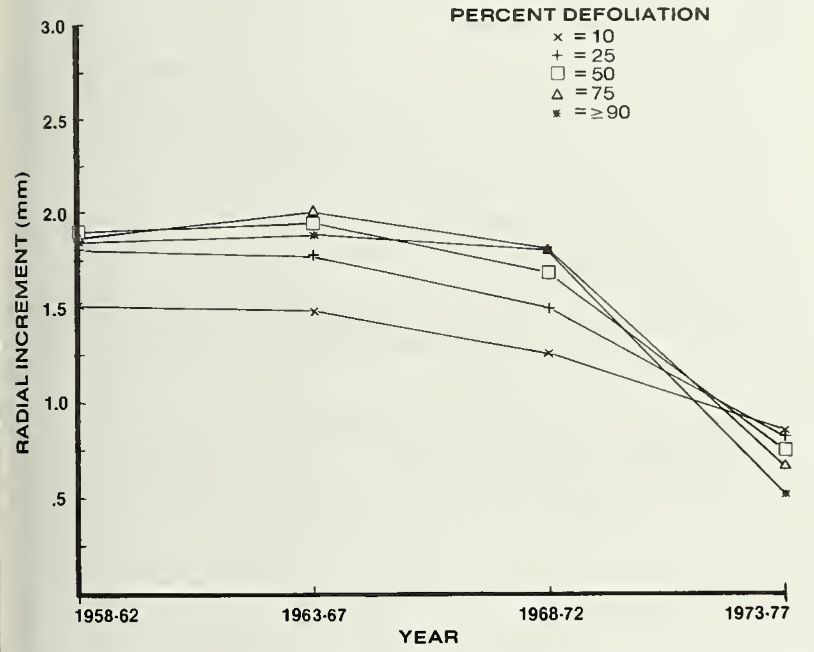

Figure 5a.--Grand fir average radial growth of individual tree classes in 5-year periodic annual increments.

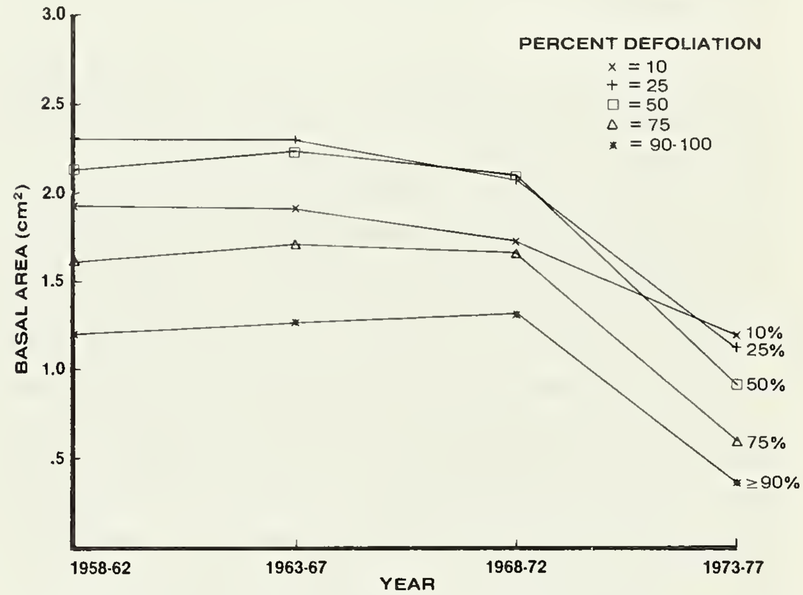

Figure 5c.--Grand fir average basal area growth of individual tree classes in 5-year periodic annual increments.

Grand fir suffering the lightest amount of defoliation (10 percent or less) had the poorest pre-outbreak growth rate, while some of the most severely defoliated trees had the highest growth rates (fig. 4a, 5a). This unusual pattern could either be real or an anomaly. When annual basal area growth is measured in square centimeters at d.b.h., this relation is reversed when graphed (fig. 5c).[1] Basal area measurements tend to reduce annual variations and compensate for declining rate of growth after a tree reaches maturity. Basal area percent growth reductions, however, were similar to our diameter percent growth reduction measurements.

A comparison of 5-year pre-outbreak with 5-year post-outbreak growth was made using regression analysis to test whether a linear relationship exists between pre- and post-outbreak growth. These linear relationships were found to be highly significant for every grand fir defoliation category and all but the 10- and 90- to 100-percent classes for Douglas-fir. Non-significance for these two categories was probably due to very small sample size. Each tree defoliation category indicated that post-outbreak growth was significantly less than pre-outbreak growth (fig. 1a-b, appendix). Post-outbreak growth for non-defoliated host (fig. 2a-b, appendix) was significantly correlated with and similar to pre-outbreak growth rates. When the linear relationships between individual tree categories are compared (fig. 6a-b), grand fir particularly shows a consistent pattern of growth declining more rapidly as defoliation increases.

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[1]This analysis was suggested and a computer program developed to convert diameter growth to basal area in square centimeters of growth by Dr. Scott Overton, Oregon State University.

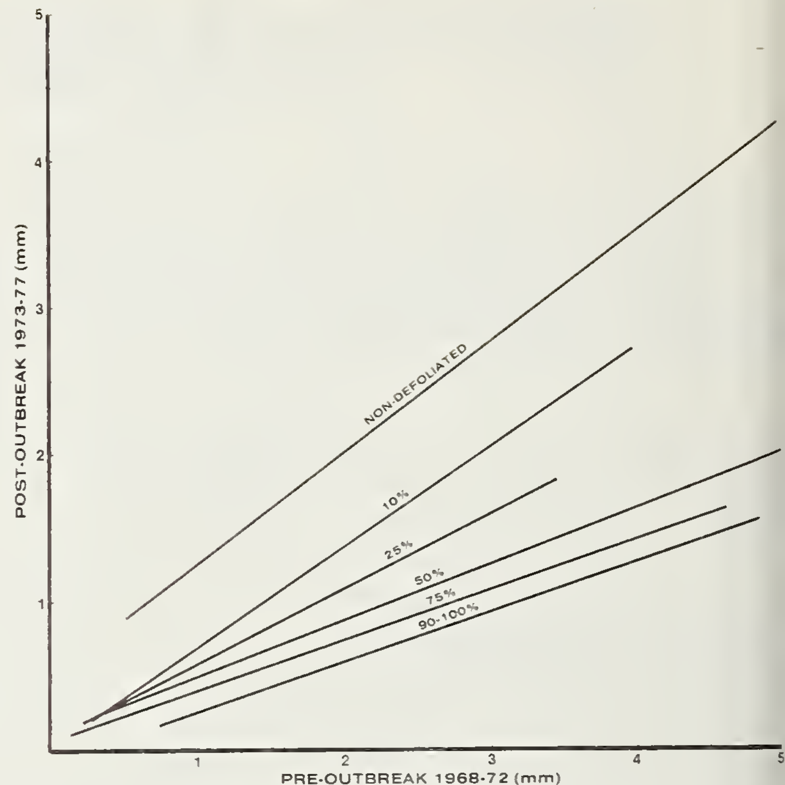

Figure 6a.--Radial growth of grand fir by percent defoliation.

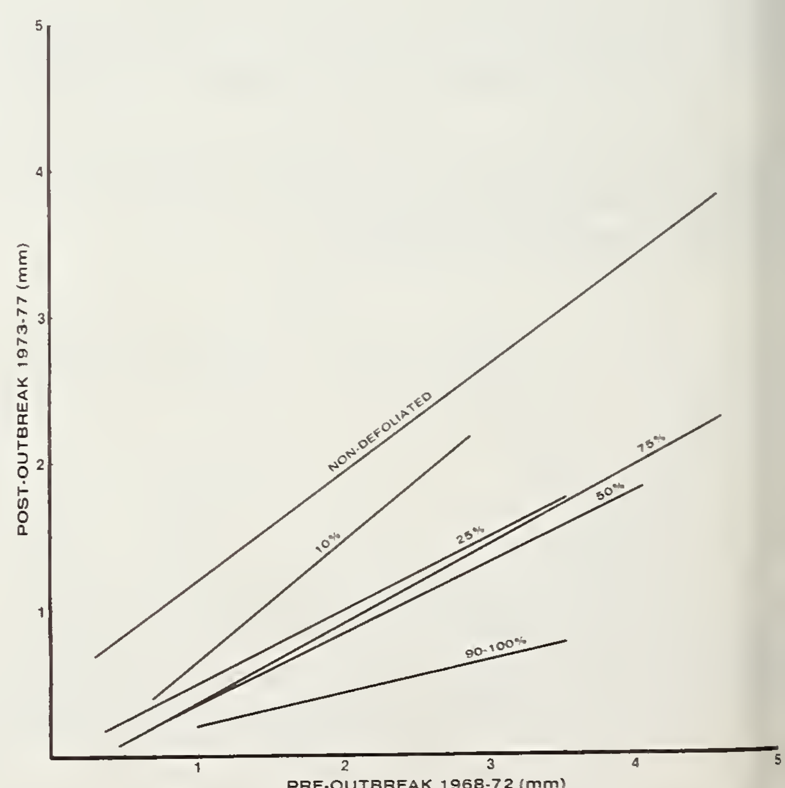

Figure 6b.--Radial growth of Douglas-fir by percent defoliation.

An analysis of covariance was used to test for differences among individual tree defoliation categories where pre-outbreak growth was the covariate and post-outbreak growth was the dependent variable compared. When testing for differences among the six defoliation categories (including non-defoliated) for grand fir, a significant difference in slope was detected. Then a comparison of all grand fir classes with ≥50-percent defoliation was made, but no difference in slope was detected (F=0.34, d.f.=2,258). A test of adjusted means, however, was highly significant (F=11.89, d.f.=2,260) indicating greater growth loss with greater amounts of defoliation (fig. 6a, and appendix 1a and 2a). When the 10- and 25-percent defoliation classes were compared, a difference in slope was detected signifying differing post-outbreak growth patterns for these two classes.

This analysis of covariance for Douglas-fir defoliation classes showed no difference in either slope or adjusted means for the 25-, 50-, and 75-percent classes. Lack of significant differences among adjusted means seems most likely due to an overall small sample for Douglas-fir. Greater growth loss, however, is again generally correlated with increasing defoliation (fig. 6b, and appendix 1b and 2b).

These analyses also indicate that growth patterns for three classes of each tree species (50, 75, 90-100 percent for grand fir; 25, 50, 75 percent for Douglas-fir) were similarly affected by defoliation. In other words, when defoliation intensity reaches 50 percent for grand fir, then the post-outbreak growth decline pattern is essentially established and remains similar for that category and any higher defoliation categories. For Douglas-fir, the critical defoliation level appears to be 25 percent; but small sample size makes this a less reliable inference.

Sample size for Douglas-fir was not equivalent to that for grand fir because Douglas-fir comprised only 20 percent of the stand on the plots. The sample size for this analysis follows:

	Individual Tree Defoliation Categories				
	10	25	50	75	90-100
	(Percent defoliated)				
Grand fir	47	158	170	64	30
Douglas-fir	4	14	23	11	7

The pre- and post-outbreak growth regression model can be useful for assigning expected growth declines to individual tree defoliation categories, stratified by trees growing at different pre-outbreak rates, for stands in the Blue Mountains.

Growth decline at d.b.h. exhibited a 1-year lag from year of defoliation. In 1972, there was little growth decline even in heavily defoliated trees indicating trees were able to continue near normal growth using stored food reserves (Kulman 1971). The lowest point of growth occurred in 1974, the year after the last defoliation. From 1975 through 1978, the growth at d.b.h. consistently increased. Higher than average precipitation in 1975 helped growth recovery. Conversely, 1976 a subnormal year and 1977 a record drought year adversely affected growth in non-defoliated trees. Precipitation records for the Blue Mountains showed about a 2.5-in departure from normal for 1976 and 1977, yet the growth trend was consistently upward for defoliated trees in contrast to the downward trend for non-defoliated samples. Reduction of inter-tree competition for sunlight and moisture resulting from defoliation and tree mortality (Wickman 1978b) and increased nutrient cycling (Klock and Wickman 1978) probably encouraged growth recovery by the 5th year after the outbreak.

Percent Growth Reduction

The amount of growth reduction caused by defoliation is an extremely difficult value to estimate because of the problems of precisely identifying and quantifying the effects of extrinsic effects other than defoliation. In the previous section we examined some possible growth trends related to precipitation. Other effects due to competition for moisture, sunlight, and nutrients are almost impossible to estimate.

An estimate of percent growth reduction for the individual tree defoliation categories was determined by using average annual radial growth for a 15-year pre-outbreak period (1958-72) and a 5-year outbreak and growth loss period (1973-77) for defoliated and non-defoliated host trees. The non-defoliated host trees are used to account for growth changes due to environmental conditions and are used as an adjustment factor to estimate expected post-outbreak growth of defoliated host trees. A ratio of actual post-outbreak growth to expected post-outbreak growth of defoliated host trees is used to estimate percent growth reduction. Graphically, this method is easily understood, and a simple formula is derived.

Assume the growth behavior of non-defoliated host trees is similar to that of defoliated host trees from the pre-outbreak to post-outbreak periods.

A = Mean annual growth of defoliated trees during the post-outbreak period.
B = Mean annual growth of defoliated trees during pre-outbreak period.
C = Mean annual growth of non-defoliated trees during the post-outbreak period.
D = Mean annual growth of non-defoliated trees during the pre-outbreak period.
E = The expected mean annual growth of defoliated trees during the post-outbreak period (i.e., assuming there was no defoliation).
R = An estimate of the ratio of actual outbreak growth to expected growth.

Assume:

$$\frac{B}{D} = \frac{E}{C}, \text{ then } E = \frac{BC}{D},\ R = \frac{A}{E},\ R_1 = \frac{A}{B},$$

$$R_2 = \frac{C}{D}, \text{ and } R = \frac{A}{E} = \frac{AD}{BC} = \frac{A/B}{C/D} = \frac{R_1}{R_2}.$$

Thus, R, an estimate of the ratio of actual outbreak growth to expected growth, is easily determined. Then, 1-R becomes a measure of growth reduction, and (1-R) x 100 is an estimate of percent net growth reduction.

The symbol R_2 is a sample adjustment factor, adjusting R_1 for various environmental effects on growth patterns. In this analysis R_2 is calculated for both host species, Douglas-fir and grand fir.

This growth loss model was applied to both diameter increment growth (millimeter) and basal area increment growth (square centimeters). The following values of R_2 serve as sample adjustment factors for determining percent radial growth loss by percent defoliation categories.

	Sample Adjustment Factors (R_2)	
	Diameter increment	Basal area increment
Grand fir	0.904	1.031
Douglas-fir	.893	.979

The relationship is shown graphically for grand fir and Douglas-fir trees defoliated 50 percent or more in figure 7a-b. Both species suffered almost identical percent net growth reduction due to defoliation, 57.9 percent for grand fir and 57.4 percent for Douglas-fir. The growth loss due to environmental factors was 9.6 percent for grand fir and 10.7 percent for Douglas-fir.

Percent growth loss for each tree defoliation category is listed in table 1.

Table 1.--Percent net growth reduction, 1973-77, by individual tree defoliation categories

Species	Defoliation	Diameter increment in mm linear growth	Basal area increment in cm^2 area growth
		Percent	
Grand fir	10	32.7	37.8
	25	45.7	50.6
	50	55.0	58.9
	75	60.7	65.5
	≥90	68.6	72.2
Douglas-fir	10	23.9	27.2
	25	45.8	47.5
	50	54.1	58.4
	75	55.8	55.6
	≥90	75.3	70.8

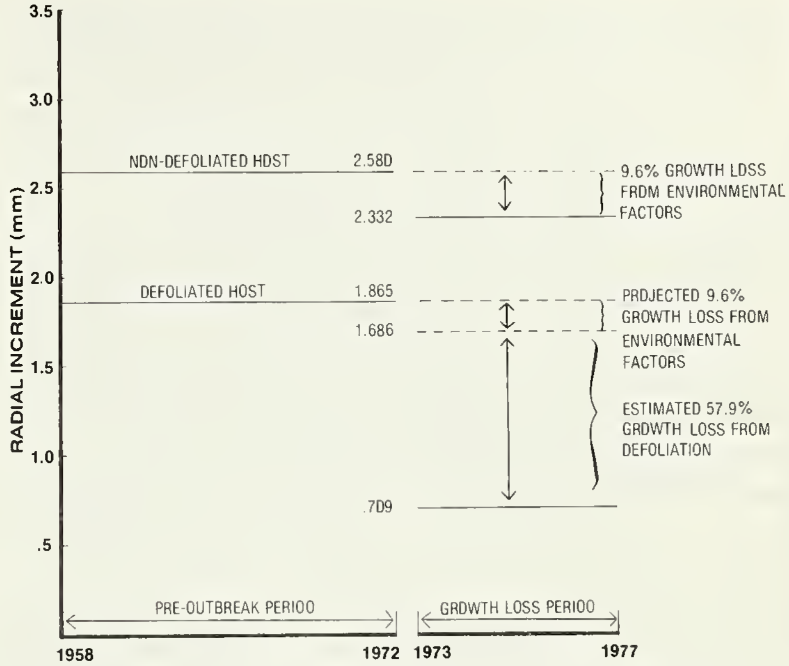

Figure 7a.--Estimated radial growth loss of ≥50-percent defoliated grand fir from tussock moth defoliation based on average radial growth for pre-outbreak and outbreak periods.

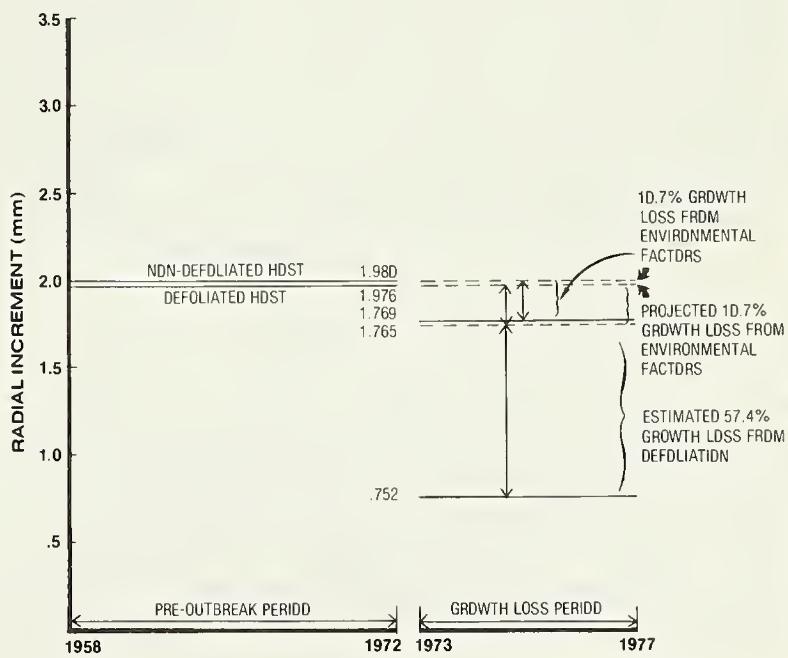

Figure 7b.--Estimated radial growth loss of ≥50-percent defoliated Douglas-fir from tussock moth defoliation based on average radial growth for pre-outbreak and outbreak periods.

Estimates of percent growth reduction are somewhat imprecise because of the complicating factors mentioned earlier. They are an important indication, however, of short-term tree damage, that is useful to forest managers. The only previous measurement of percent growth reduction following DFTM defoliation was made after a California outbreak (Wickman 1963). In that case, the reduction during the year following defoliation was calculated as a percentage of the average annual growth during the four years immediately preceding defoliation. Non-defoliated trees also declined slightly during the infestation period, but no record was made of the amount. Most studies of growth decline suffer from this inability to account for environmental effects and to deduct those effects from the gross amount lost after defoliation. In the California study, heavily defoliated trees (50-percent or greater defoliation) suffered 74-percent unadjusted (R_1) growth loss during a 4-year post-outbreak period. In this study, grand fir $\geq$50-percent defoliated suffered an unadjusted growth loss of 62 percent during a 5-year post-outbreak period. This is similar to the California outbreak except recovery was a year later in the Blue Mountains and this may have been influenced by the 1977 drought.

The short-term growth reductions found after defoliation by the DFTM in the Blue Mountains are strikingly similar to those found after other outbreaks (Wickman 1963, 1978b, Brubaker 1978). The effects on growth are immediate and pronounced for most degrees of defoliation, and recovery seems to take place shortly after defoliation ceases.

Diameter Classes

All defoliated trees were separated into five diameter classes and compared. Growth trends were similar for most diameter classes except for grand fir 1-6 inches in diameter which suffered the lowest growth rate in 1974 and 1975 (fig. 8a-b). For both species, small poles (13- to 18-in diameter) had the fastest growth rates before and recovery after defoliation, while the largest trees (>24-in diameter) had the slowest recovery rates.

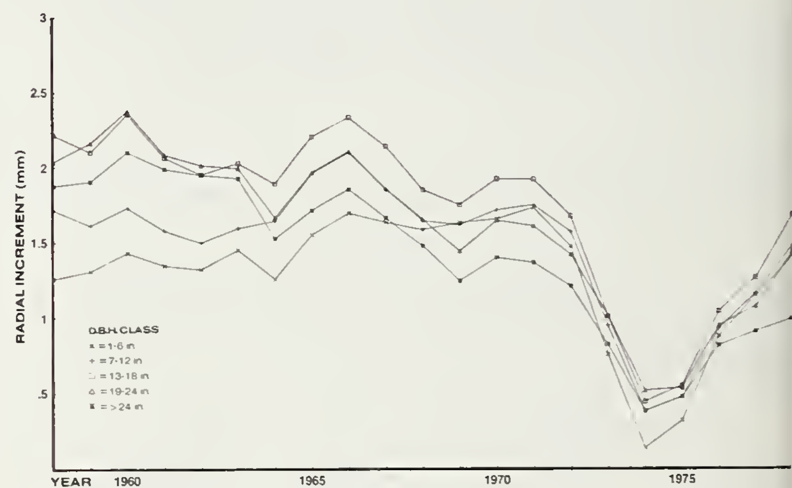

Figure 8a.--Average radial growth of grand fir by d.b.h. class.

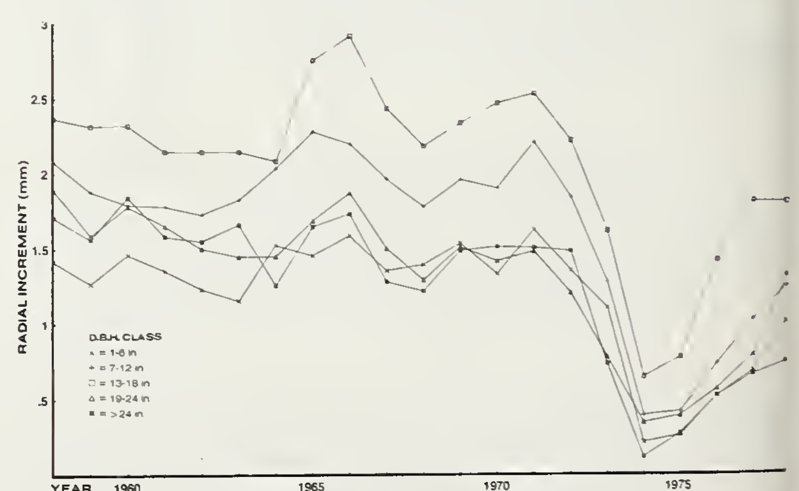

Figure 8b.--Average radial growth of Douglas-fir by d.b.h. class.

The number of sample trees for each of the d.b.h. classes is given below:

	D.b.h Class				
	1-6	7-12	13-18	19-24	>24
	(Inches)				
Grand fir	31	206	86	62	84
Douglas-fir	5	21	15	8	10

The distribution of d.b.h. by 1-inch intervals for all defoliated and non-defoliated host trees is presented in the appendix (table 2). The sample is biased toward the larger trees in the stands since we sampled only dominant and co-dominant trees which tend to be largest.

Top-Kill Classes

Top-kill is a common result of tussock moth outbreaks, and in the Blue Mountains 8.4 percent of the grand fir and 16.4 percent of the Douglas-fir suffered top-kill. Two percent of each species suffered top-kill amounting to 25 percent or more of the crown (Wickman 1978a). A tabulation was made of top-killed trees in our sample to analyze the effects of top damage on radial growth. Our sample size for classes of top-kill follows:

	Top-Kill Class		
	None or leader only	1-25%	>25%
Grand fir	332	70	21
	None or leader only	Top-killed	
Douglas-fir	39	8	

Grand fir with 25 percent or less top-kill exhibited the same relative growth decline and slightly better recovery than trees with no top-kill. Trees with top-kill exceeding 25 percent showed less than half the growth recovery by 1978 as trees with no top-kill (fig. 9a). The top-killed grand fir were also growing at a faster rate prior to the outbreak than the trees without top-kill. Since most top-kill occurred in trees defoliated 75 percent or more, this indicates that perhaps the most vigorous trees (fastest growing) were supporting the highest tussock moth populations.

Figure 9a.--Average radial growth of grand fir by top-kill class.

The sample size for Douglas-fir was so small that all top-killed trees were included in one class. The eight top-killed Douglas-fir showed a similar growth decline and slower recovery than trees with no top-kill (fig. 9b).

Figure 9b.--Average radial growth of Douglas-fir by top-kill class.

Comparison of 1 Versus 2 Years of Defoliation

The effects of 1 year of severe defoliation versus 2 years on growth of grand fir and Douglas-fir were determined for trees defoliated 50 percent or more. The sample size was as follows:

	Defoliated ≥50 percent	
	1973 only	1972 and 1973
Grand fir	45	128
Douglas-fir	24	11

The growth patterns for both classes of grand fir are similar until 1973. At that time, the trees defoliated 50 percent or more in 1972 and again in 1973 exhibited a sharp decline while those defoliated 50 percent or greater only in 1973 did not sharply decline until 1974 (fig. 10a). After 1974, recovery was almost identical for the trees defoliated only 1 year and those defoliated 2 years.

Douglas-fir trees in the two classes had a different growth pattern than grand fir (fig. 10b). Trees defoliated 50 percent or more in 1972 and then defoliated again in 1973 were slower growing prior to the outbreak and exhibited slower recovery. This might indicate that Douglas-fir growth was more seriously affected by the 2 years of defoliation than grand fir since they also suffered proportionally more top-kill and mortality in the outbreak (Wickman 1978a). This sample size (11 trees) is small, however; and other Douglas-fir growth patterns are similar to grand fir. For instance, we did not find that grand fir suffered a greater and differential rate of growth loss as reported by Williams (1966, 1967) after defoliation by western spruce budworm in the Blue Mountains. Our results agree with Brubaker and Greene (1979) who failed to find differences in growth of the two species in Idaho after tussock moth defoliation.

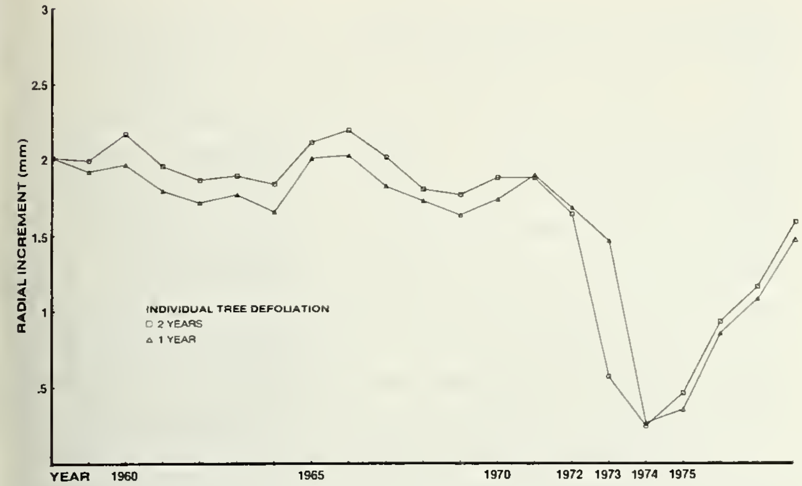

Figure 10a.--Average radial growth of grand fir defoliated in 1972-73 and defoliated in 1973 only.

Figure 10b.--Average radial growth of Douglas-fir defoliated in 1972-73 and defoliated in 1973 only.

Comparison of All Defoliated Versus Non-Defoliated Trees

Growth fluctuations caused by extrinsic factors are difficult to identify because there are usually several factors affecting tree growth in the same year. The effects of defoliation are usually so severe they conceal the effects from other causes such as precipitation. Therefore, a sample of trees which were not defoliated provides some indication of growth anomalies occurring during the outbreak and post-outbreak years without the obscuring effects of defoliation. To determine normal growth patterns during the outbreak and post-outbreak period, non-host trees, ponderosa pine, western larch, and Engelmann spruce, occurring on the defoliated plots were sampled. Even these trees, however, suffered defoliation in the severely defoliated stands. Therefore, five areas adjacent to the outbreak containing non-defoliated host trees, were also sampled. A tabulation of non-host trees sampled on the plots showed there were 56 pine, 12 larch, and 21 spruce. The total defoliated and non-defoliated host trees is given below:

	Defoliated	Non-defoliated
Grand fir	470	32
Douglas-fir	60	38

The non-host trees on the plots exhibited growth declines during the immediate post-outbreak period, 1973 and 1974, which may have been due in part to defoliation (fig. 11). All three species showed growth increases in 1976, the year after a good precipitation year, then a decline in 1977, a subnormal precipitation year, with larch and spruce continuing their decline into 1978.

Figure 11.--Average radial growth of non-host trees.

There are other problems with using data from these non-host plot trees beyond 1974. Non-host trees on the plots are showing some growth effects from other extrinsic factors, namely reduced tree competition for sunlight, moisture, and nutrients caused by intermingled host mortality in the severely defoliated stands. There are also increased nutrients from leaf litter fall and insect frass as a result of defoliation (Klock and Wickman 1978). These trees may be of more interest in long-term measurements of effects; but for this study, their value is limited to exhibiting pre-outbreak growth patterns.

The sample of 21 pines from a pure pine stand on a dry ridge surrounded by defoliated stands provides additional insight into the effects of environment on growth. Because these trees are located on a dry site, they are more sensitive to soil moisture changes regulated by precipitation and reflect these changes readily in their growth patterns (Fritts 1976). The year of greatest depressed growth of the pine, 1974, also coincides with the year of greatest growth reduction of defoliated fir (fig. 12). This indicates that unfavorable environment compounded the effects of defoliation. In 1976, the pine exhibited greatly increased growth as did defoliated and non-defoliated fir (fig. 13). Therefore, environment also played a positive role in the recovery of defoliated trees for at least 2 years after the outbreak.

Figure 12.--Annual diameter growth of ponderosa pine from a dry ridge surrounded by defoliated stands.

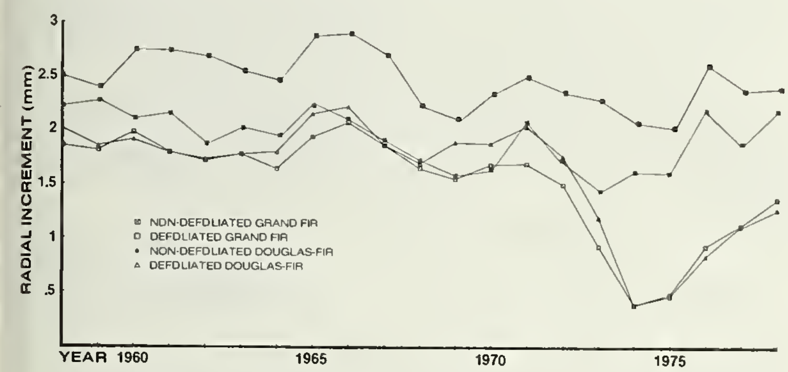

Figure 13.--Average radial growth of all defoliated and non-defoliated grand fir and Douglas-fir trees.

The growth configurations of non-defoliated host trees adjacent to the defoliated areas illustrates the typical expected growth during the post-outbreak years (fig. 13). There is, however, a complicating factor inherent in this sample. The non-defoliated grand fir has a much faster growth rate than the defoliated grand fir because the only place non-defoliated stands contiguous to the outbreak could be found were canyon bottoms. These sites had deeper soil, cooler temperatures, and more soil moisture than the outbreak areas. Consequently, the non-defoliated grand fir were fundamentally more vigorous trees than the defoliated grand fir. They did show downward growth trends in 1972, 1973, 1974, and 1977, however; this is probably related to lower precipitation during those years.

The non-defoliated Douglas-fir came from drier sites, and the growth pattern is similar to both defoliated grand fir and Douglas-fir through 1972. In 1973, 1974, 1975, and 1977, non-defoliated Douglas-fir had lower than normal growth; and this, too, was most likely associated with subnormal precipitation during the same years (fig. 14). It is also interesting to note that every class of non-defoliated tree had a growth decline in 1977, a record drought year for the Pacific Northwest; but every defoliated tree class exhibited some growth recovery that same year. This seems unusual for trees which had suffered such recent physiological shock and slow recovery and may lend additional credence to observations that decreased competition and increased nutrient cycling enhances tree recovery after outbreaks (Wickman 1978b).

Figure 14.--Annual precipitation at Meacham, Oregon. (Adjusted from Gibbon, Oregon, annual precipitation.)*

Growth Related to Stand Defoliation

The growth study was designed primarily to examine the effects of defoliation on individual trees. Amount of defoliation was chosen as the variable most useful for predicting tree damage. The arrangement of study plots within aerially mapped damage classes and the ground plot defoliation classification allowed us to make some inferences on damage to the stand as well as to individual trees (Wickman 1978a). Rapid salvage logging of the most severely defoliated stands, however, resulted in the loss of most of our class 1 (heavy) plots and negated our replicated plot design. Substitute plots, severely defoliated, were established in other areas and used for individual tree analysis. The growth reductions classified on a stand basis reported here were not statistically tested; however, they are presented for comparisons with earlier reported work on tree mortality and top-kill (Wickman 1978a).

Aerially Mapped Defoliation Classes

Pest managers used four aerially mapped classes to stratify the outbreak. When radial growth for each class was graphed (fig. 15a), the heavy, moderate, and light classes of grand fir defoliation had almost identical growth patterns both before and after the outbreak. The very light class, where defoliation was observed only in 1973, had a 1-year lag before growth declined; but rate of recovery was similar to the other classes. One reason for the almost identical growth configurations in all four classes was that the aerially mapped classes were broadly delineated and contained a mixture of two or three defoliation classes. The similarity among the aerially mapped defoliation classes was also noted in the summary of tree mortality and top-kill for the outbreak (Wickman 1978a).

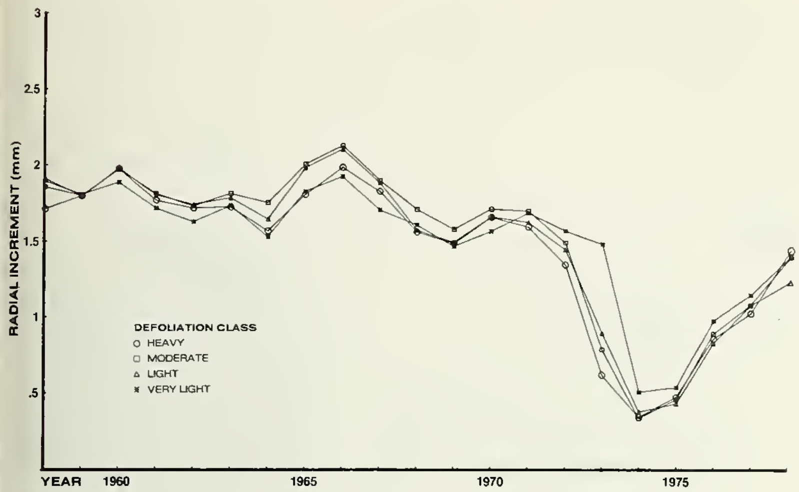

Figure 15a.--Average radial growth of grand fir by aerially mapped defoliation classes.

For Douglas-fir, the differences are more pronounced and strongly related to amount of defoliation. The pre-outbreak growth was best in the very light defoliation class, and growth decline was greatest in the moderate defoliation class (fig. 15b).

The sample size is tabulated below for both species:

	Aerially Mapped Defoliation Classes[2]			
	Heavy	Moderate	Light	Very light
Grand fir	78	176	106	80
Douglas-fir	--	14	12	22

[2]Sample sizes differ from those on page 3 because of plot qualification used for this analysis.

Figure 15b.--Average radial growth of Douglas-fir by aerially mapped defoliation classes.

Ground Plot Defoliation Classes

When the plots are stratified by ground defoliation measurements rather than broadly mapped from the air, some growth relations also differ. The patterns of grand fir growth remain similar for very light, light, and moderate defoliation classes; however, the heavy defoliation class is now distinctly different because only severely defoliated plots are included (fig. 16a). The tabulation of sample trees in the four classes is given below:

	Ground Plot Defoliation Classes[3]			
	Heavy	Moderate	light	Very light
Grand fir	20	283	93	73
Douglas-fir	--	25	13	21

[3]Sample size differs from those on page 3 because of plot qualification used for this analysis.

Figure 16a.--Average radial growth of grand fir by ground plot defoliation classes.

Figure 16b.--Average radial growth of Douglas-fir by ground plot defoliation classes.

In this method of stratification, only 20 severely defoliated grand fir were sampled (compared to 78 trees in the aerially mapped heavy class); but they were selected only from several areas that suffered measured heavy defoliation. With this method of stratification, most of the increase in grand fir sample size occurs in the moderate class, with an increase from 176 trees in the previous analysis to 283 trees in this analysis.

The grand fir in the heavy defoliation class had the best growth rate prior to the outbreak, suffered the sharpest and most severe growth decline, and also recovered most rapidly and completely (fig. 16a). The striking growth recovery of trees in heavy defoliated areas is not unexpected because tree mortality averaged 72 percent of the stand in these areas (Wickman 1978a); consequently, inter-tree competition was drastically reduced.

There is no sample of the heavy defoliation class for Douglas-fir. Growth patterns for light and moderate classes are similar to those for the same classes of grand fir; however, the very light class shows the best pre-outbreak growth (fig. 16b).

The growth patterns of defoliated stands generally conformed to those reported for individual trees. Specifically, growth reduction was proportional to degree of defoliation.

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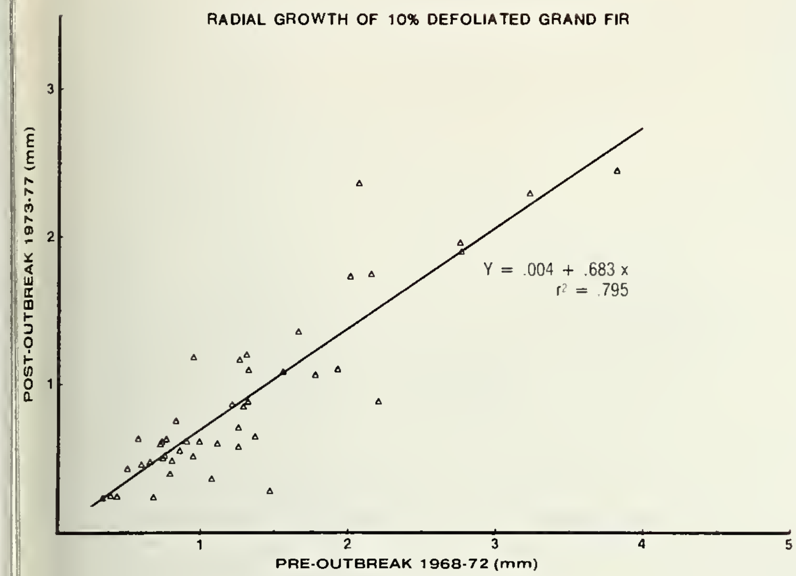
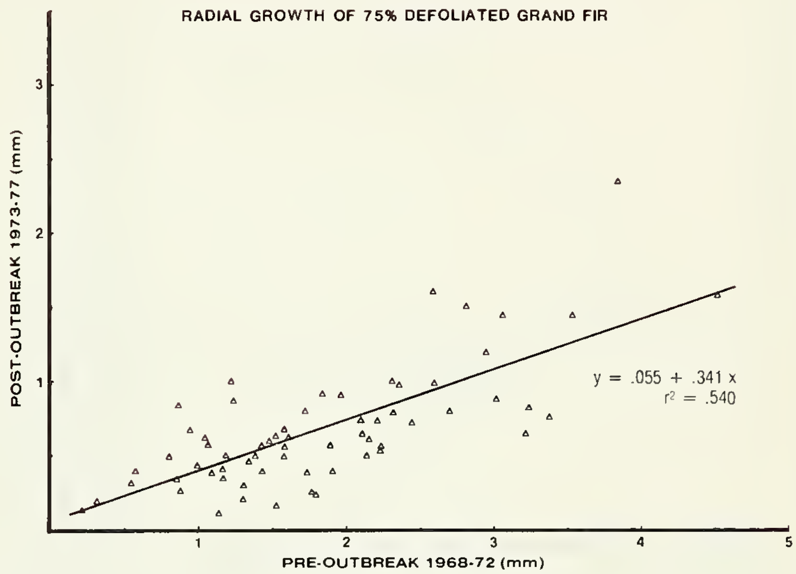
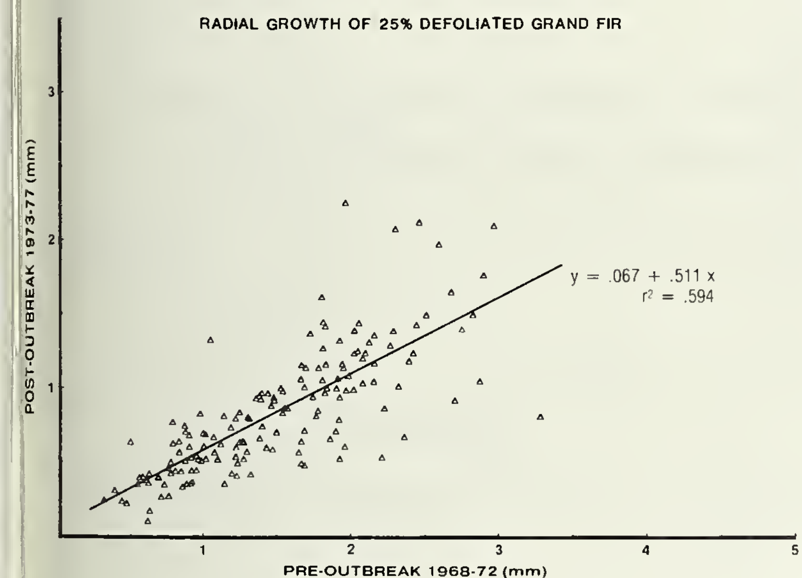
Appendix

Table 2.--Distribution by 1-inch diameters for all defoliated and non-defoliated host trees

D.b.h.	Grand fir		Douglas-fir	
	Defoliated	Non-Defoliated	Defoliated	Non-Defoliated
1	1	0	0	0
2	3	0	0	0
3	8	0	0	0
4	8	0	2	0
5	6	0	0	0
6	13	0	6	0
7	30	0	5	0
8	29	0	3	0
9	35	0	1	0
10	46	1	4	1
11	38	0	4	0
12	29	5	3	3
13	19	0	3	2
14	24	5	2	5
15	15	0	4	1
16	9	9	2	4
17	5	1	1	3
18	15	8	1	8
19	13	1	4	0
20	15	3	0	1
21	8	0	1	0
22	7	1	1	2
23	9	1	0	0
24	5	2	2	0
25	9	0	1	0
26	7	0	2	3
27	8	0	0	0
28	7	1	0	2
29	6	0	1	0
30	2	1	0	0
31	6	0	0	0
32	5	1	0	2
33	7	0	2	0
34	3	0	1	0
35	3	0	0	0
36	6	0	0	0
37	1	0	0	0
38	1	0	0	1
39	1	0	0	0
40	2	0	1	0
41	6	0	0	0
42	2	0	0	0
43	0	0	0	0
44	0	0	0	0
45	0	0	1	0







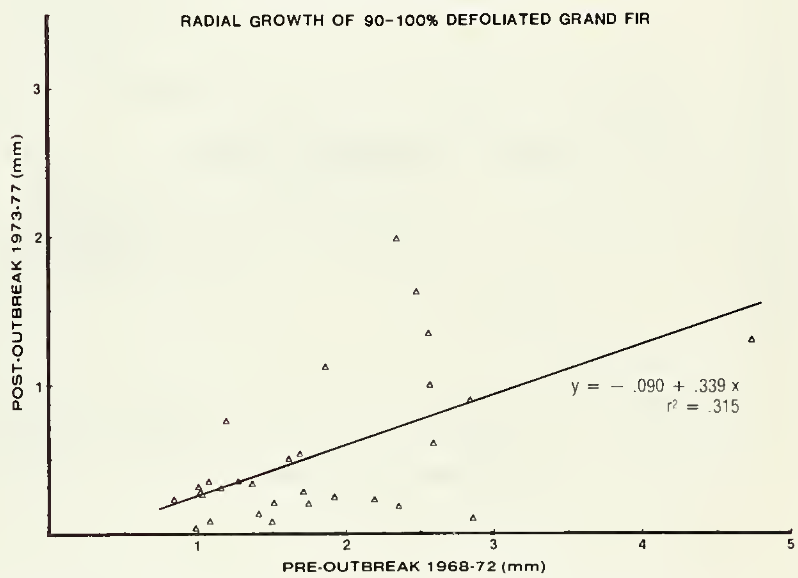
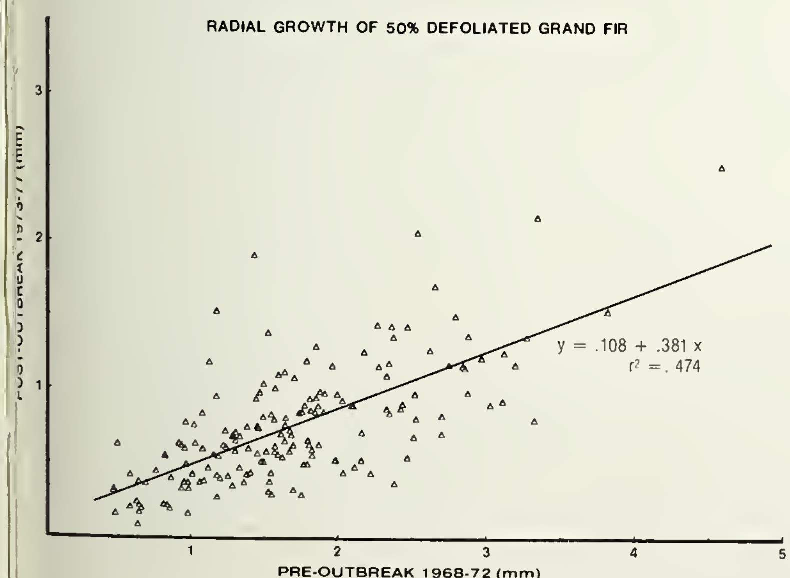
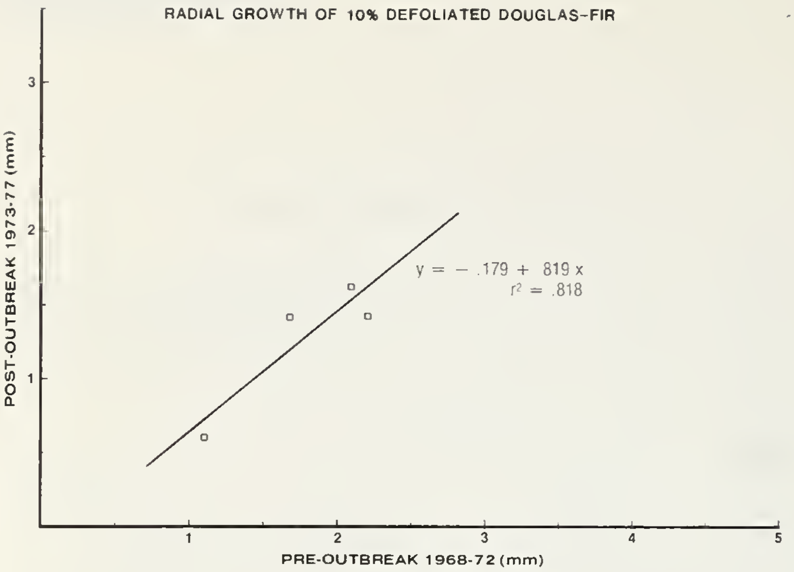
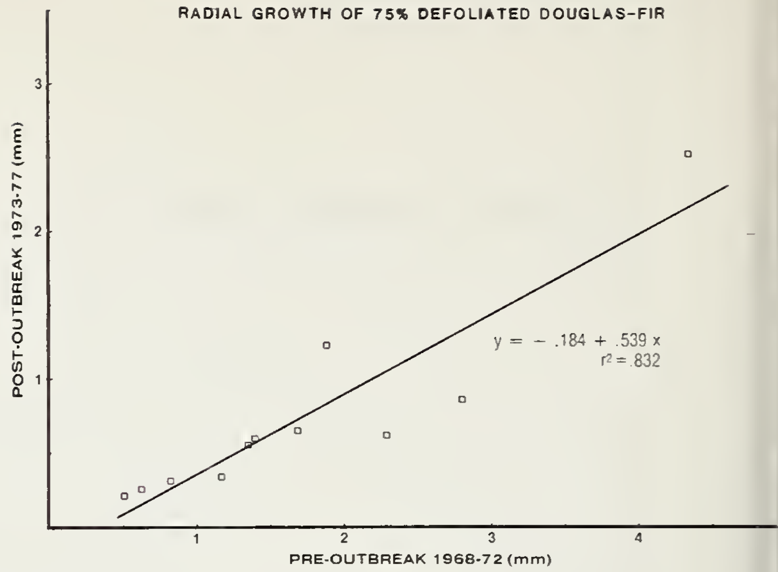
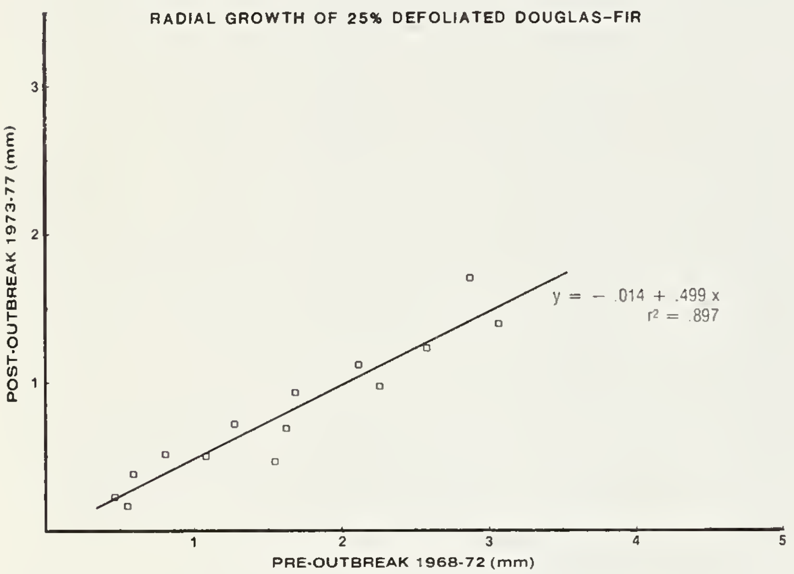


Figure 1a.--Radial growth of defoliated grand fir.









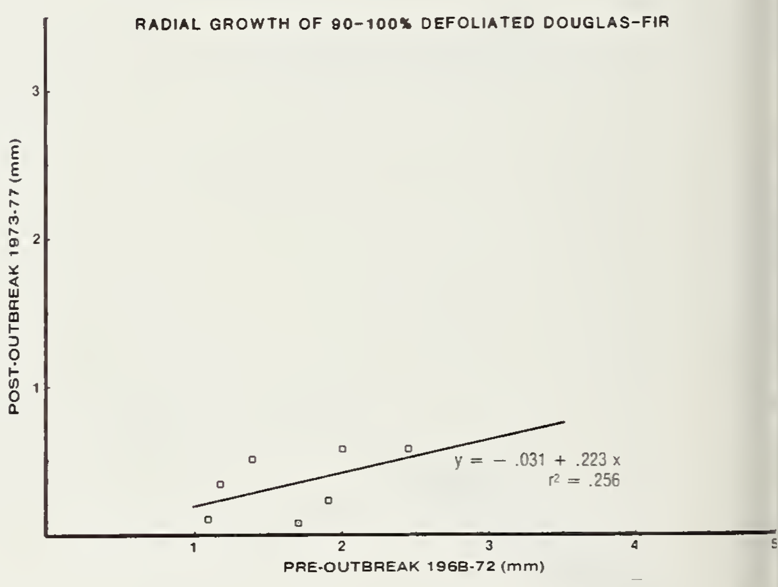
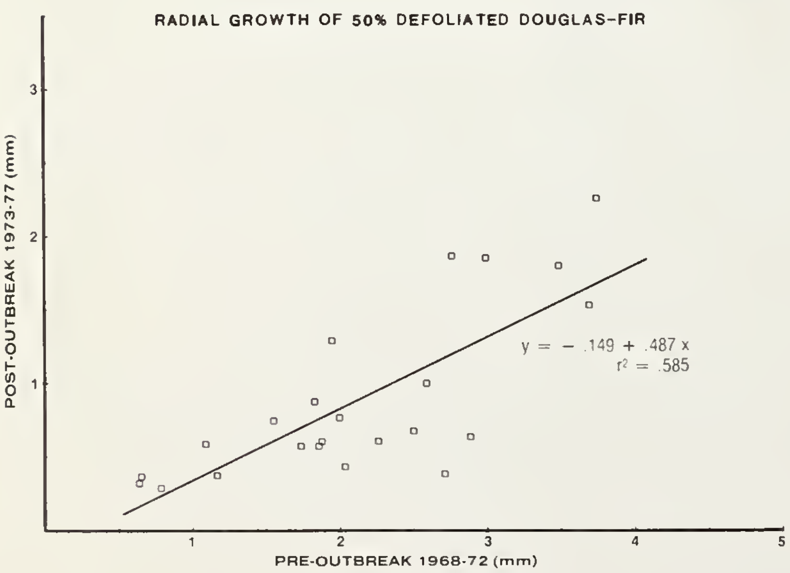


Figure 1b.--Radial growth of defoliated Douglas-fir.



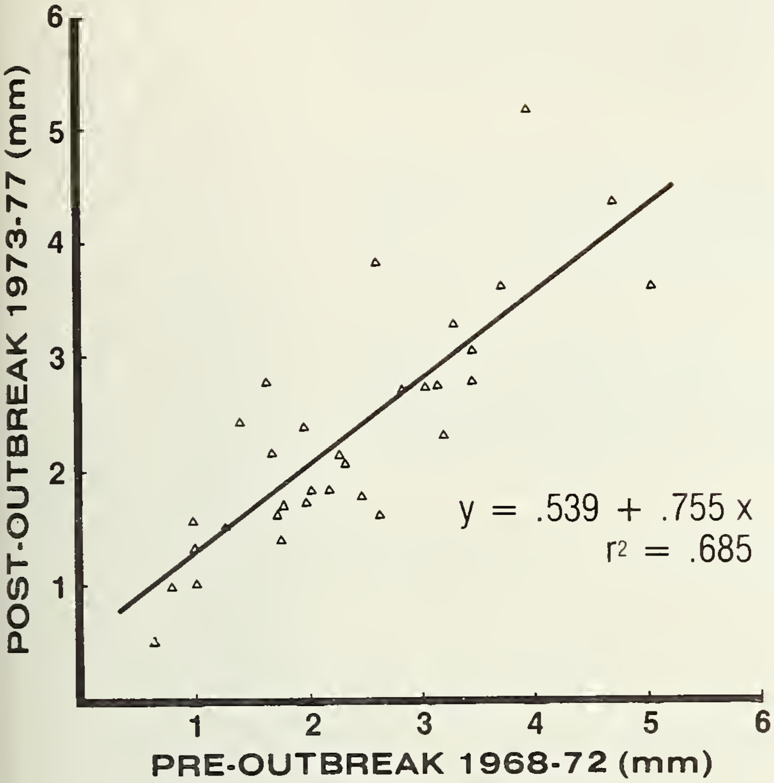


Figure 2a.--Radial growth of non-defoliated grand fir.

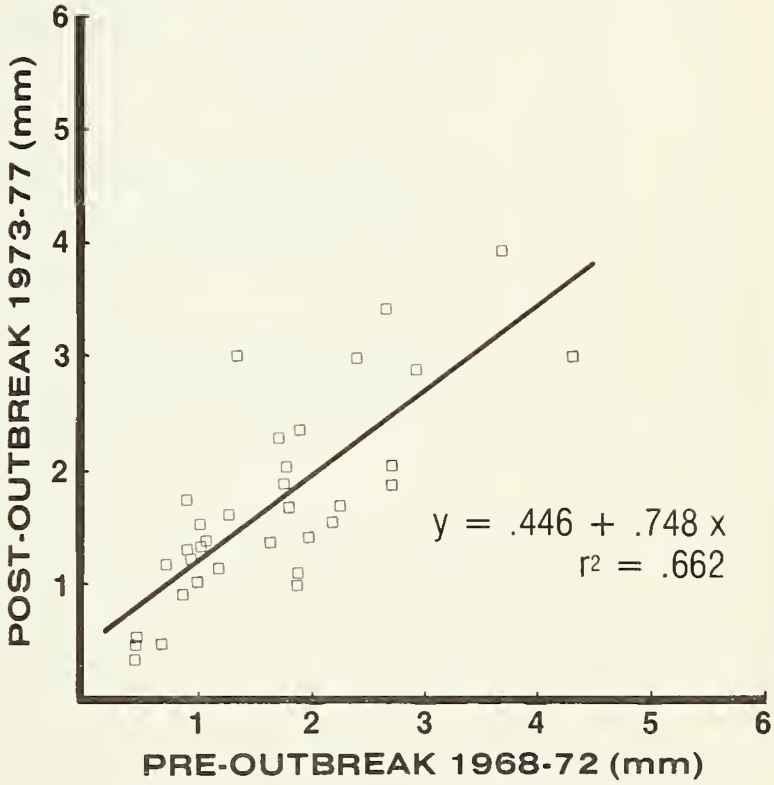


Figure 2b.--Radial growth of non-defoliated Douglas-fir.

☆ U.S. Government Printing Office: 1980— 699-169/189

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1980. Radial growth in grand fir and Douglas-fir related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. USDA For. Serv. Res. Pap. PNW-269, 23 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Radial growth reduction related to amount of tree defoliation was studied following a severe tussock moth outbreak. Growth sharply declined the year after defoliation began, and amount of decline was proportional to percent defoliation. Growth recovery began the year after defoliation ceased and radial increment had returned to pre-outbreak levels 5 years after defoliation.

KEYWORDS: Increment (radial), defoliation damage, insect damage (-forest, Douglas-fir tussock moth, *Orgyia pseudotsugata*, grand fir, *Abies grandis*, Douglas-fir, *Pseudotsuga menziesii*, Oregon (Blue Mountains), Washington (Blue Mountains).

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